Perception and Cognition of Different Types of Graphic Notations as a Source of Information in Applied Informatics

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Abstract—**Various forms of graphical notations are often used to depict different areas/domains of human knowledge. One of the forms to record the steps of data processing in information engineering is workflow diagrams; to record organization and representation of knowledge in the form of concepts and their interrelations, concept maps are used. Perception and cognition of graphic information depend on personality characteristics of the diagram's reader. Different approaches to perception and cognition of graphic notations can be measured and evaluated with the use of eye-tracking device. For the purposes of this research the cognition was examined in two areas: workflow diagrams of geographic information systems and physics related concept maps.**

Keywords: workflow diagram; concept maps; eye-tracking; information engineering.

I. Introduction

Advanced technical devices and software development in the field of applied informatics retroactively supports the development of other fields of information technology. One example being the research of graphic notations of workflow diagrams with the use of eye-tracking devices. Recently, eye-tracking testing has been one of the favorite methods of researching image (stimulus) following by respondents, due to its high precision and objective results.

Programs provided with eye-tracker equipment allow automatic assessment of gaze. Eye-tracking metrics, such as fixation duration, saccade amplitude, scan path length or dwell time, are derived from basic eye-events (fixations and saccades). The software automatically calculates the total test time, records mouse clicks, time to the first click, blinks and visualizes heat (attention) maps etc. From statistical analysis of eye-tracking, quantitative characteristics allow to indicate respondent's tactics or cognitive load during stimulus task solving [1]. Stimulus could be a photograph, picture, map or diagram.

Studies published in psychological literature prove that users react to presented information differently depending on the presentation method [2]. Measuring with eye-tracking equipment shows readers use different techniques to retrieve information from diagrams. The techniques discovered should inform the creation and design of diagrams to facilitate easy readability and understanding for all users. Creation of diagrams for both workflow diagrams for geographic information systems (GIS) and concept maps is supported today by graphic editors for automated creation. Graphic notation of this software helps or limits the graphic form of the diagrams.

The research presented here describes two eye-tracking experiments on diagram reading. The first deals with workflow diagram from software ArcGIS for Desktop, in which the procedure of data processing is made in component ModelBuilder. The research focuses on algorithm for gradual processing of spatial data. The workflow is first used as a batch process or secondly as repetitive data processing for another data from different space (region, district) or time.

The second experiment focuses on testing and retrieving and processing information from a concept map. Software CmapTools was used to create concept map with the topic of the Atom (Fig. 5). During the eye-tracker testing, respondents were given two tasks, which represented different cognitive levels of work. These tasks were testing central domain reproduction field (Task 1) and complex mental operation field (Task 2).

II. Material and Methods

A. Workflow Diagrams in GIS

One of the most common ways to note the steps of data processing in information engineering is to use workflow diagrams. Workflow diagrams consist of graphic entities that represent data and operations. These are connected with oriented lines (connectors) that end with arrows. Lines show the direction of the process. GIS software currently includes graphic editors that allow the creation of workflow diagrams. They are ERDAS, IDRISI, ArcGIS, AutoCAD Map and QGIS. Overview and detailed description of

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graphic notations is available in literature and user manuals [3].

B. Concept Maps

Knowledge attained by humanity should be passed on to next generations in a sensible form and extent, so that they can build upon it and expand it, or reevaluate it and arrive at other, better solutions. Scientific knowledge has its inner logical structure, it is based on key terminology of the given science discipline and on series of assertions by researches and their scientific explorations.

Concept map is a diagram showing the relationships between concepts. Concept maps are graphic tools for organizing and representing knowledge [4]. Concept maps were developed in 1972 in the course of Novak's research program at Cornell University, where he sought to follow and understand changes in children's knowledge of science [5]. During the course of this study the researches interviewed many children, and they found it difficult to identify specific changes in the children's understanding of science concepts by examining interview transcripts. This program was based on learning psychology of David Ausubel [6, 7]. The fundamental idea in Ausubel's cognitive psychology is that learning takes place by *assimilation* of new concepts and propositions into existing concept and propositional framework held by the learner. This knowledge structure as held by the learner is also referred to as the individual's *cognitive structure*. Out of the necessity to find a better way to represent children's conceptual understanding emerged the idea of representing children's knowledge in the form of a concept map. Thus was born a new tool not only for use in research, but also for many other uses.

Concept maps were developed to enhance meaningful learning in sciences. Construction of concept maps includes concepts that are usually enclosed in circles or boxes of some type, and relationships between concepts indicated by the connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between these two concepts [8].

C. Perception and Cognition of Graphic Notations

At the dawn of civilization it was the image that was the first attempt to represent reality. After development of verbal communication (oral at first, later graphically fixed), images together with text represent specific objects, phenomena and events – becoming their external representation. Readers of the text and observers of the image should themselves construe the correct inner mental representation of the content that image and text strive to convey. However images and text differ from each other significantly: whereas verbal text stems from natural language and is symbolical, image has a visual character[1] – it has to be similar to the portrayed object or phenomenon [9]. A visual notation consists of a set of graphical symbols, a set of compositional rules and definitions of the meaning of each symbol [10].

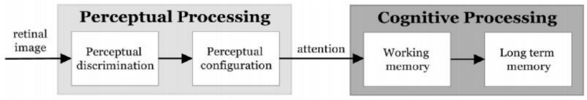

Figure 1. Perceptual and cognitive processing of diagrams [10]

D. Multiple Intelligences Theory

It is difficult to define the term intelligence. It is connected not only with types and processes of thinking, but with memory and verbal expression. From systemic approach, intelligence can be defined as "performance level in certain area. It is a result of specific interplay of abilities, personality characteristics and sociocultural context" [11]. H. Gardner [12] defines intelligence as the "ability to solve problems or create products that have a certain value in one or more cultural environments".

Components of intelligence are relatively independent of each other and may be further supported and improve, or ignored and decline. Each intelligence has different ways of perception, acceptance and processing of information, different methods of retention. Individual intelligences are located in different parts of the brain and may work independently or together. They are inherent, and may be altered and partially developed [13].

To determine personality characteristics of respondents a questionnaire of Multiple Intelligences Test has been used, translated to Czech and then reverse translated to English [14]. The first translation has been corrected according to the result of reverse translation. The questionnaire includes 70 items, in which respondents show the level of agreement with individual items. Individual questions are purposely aimed to determine the specific type of intelligence. The following types of intelligences are evaluated in the questionnaire:

1. language (lang.)
2. music (music)
3. mathematical (math.)
4. visual (vis.)
5. motoric (mot.)
6. interpersonal (inter.)
7. intrapersonal (intra.)

This instrument is a simple directly reflective assessment tool which works in a single dimension. That is, the results are produced directly from the inputs (the scored answers to the statement questions). There are no complex computations or correlations or

[1] For the purpose of this article, we understand visual representation as messages in form of graphs, diagrams, but also images in the sense of "visual art".

scaling. As such it less prone to distortion or confusion than a more complicated testing methodology might be, especially one involving convoluted formulae or scales on several dimensions [14].

E. Eye Trackers and Eye-Tracking Software

Among worldwide most used eye-tracking devices are devices by TOBII and SMI companies. For experiments at the Palacky University in Olomouc, we used SMI RED 250 with software SMI Experiment Suite 360°. To define the test, we used SMI Experiment Center program; to visualize the results we used SMI BeGaze. The evaluation was also done in software Ogama 4.4 [15].

At the University of Ostrava, we used Tobii TX 300 Eye Tracker, and the data was collected and analyzed using Tobii Studio software. The Tobii 300 tracks eye movements at a resolution of 1920x1080 pixels at a controller refresh rate of 300 Hz [16].

Eye-tracking methodologies allow the researchers to capture the reader's eye movements, as well as their fixations (200–300 millisecond pauses) as text is read [17]. Saccadic movements between graphic elements and fixation times provide insights into comprehension. Where a reader directs, saccadic movements reveal their attention, and how much attention is allocated is disclosed by fixations [18].

III. Results and Discussion

A. Experiments with Workflow Diagrams

In 2014 in eye-tracking laboratory at Palacky University, 21 students were tested. They were 1st year students of a master's program, therefore having more than 3-year experience of using the ArcGIS software. Methods used and operations with spatial data were part of their basic knowledge. Creating models in the component ArcGIS ModelBuilder has been known to them since the 2nd year of their bachelor studies, i.e. circa 2 years. The test comprised of series of 12 diagrams, where each diagram represented one test assignment. Respondents answered by clicking on the diagram or provided text answers. When answering by clicking, multiple correct answers (clicks) were possible. The questions revolved around finding and highlighting certain operations in the diagram, highlighting input and output data, variables, etc. An example of one of the testing diagrams is show in Fig. 2.

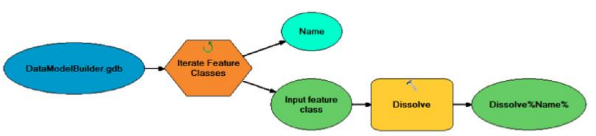

Figure 2. Stimulus - workflow diagram No.10 from ModelBuilder used in the eye-tracking test series

Questions accompanying the diagrams were relatively easy, and respondents should mostly follow the graphic symbols in the diagram. Due to questions' simplicity, we did not expect to receive a significant amount of incorrect answers. Test results were presented in charts, as well as heat maps, scan paths, etc.

Heat map example of stimulus No.10 can be seen in Fig. 3. In this question, respondents were supposed to find a diagram element that uses dynamic variable. The correct answer by mouse click is depicted by black circle in the heat map. Dynamic variable is labeled with text using the symbol %. The green oval included the text "Dissolve%Name%". The respondent should therefore decide by both the graphic symbol of oval, and by closely following the text in it. The largest attention is on an orange rectangle in the heat map, but the second largest attention is on the oval, where the correct answer is. The most intense attention on the orange symbol is apparently caused by the way the diagram is read – from left to right, the same as reading written text. Scan path records from the eye-tracking device confirm that respondents do read the information from left to right. However, the reading does not begin top left, but farther away from the left edge of the diagram. Large amount of fixations therefore rest on the second element – the orange hexagon, where most respondents begin their reading. Total of 14 respondents answered the question No. 10 correctly, 5 respondents answered incorrectly (graph in Fig. 4). Total results of all 21 respondents in terms of correct and incorrect answers to all the 12 test diagrams can be found in Fig. 4.

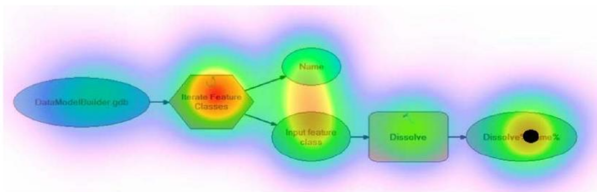

Figure 3. Heat map of the workflow diagram No.10

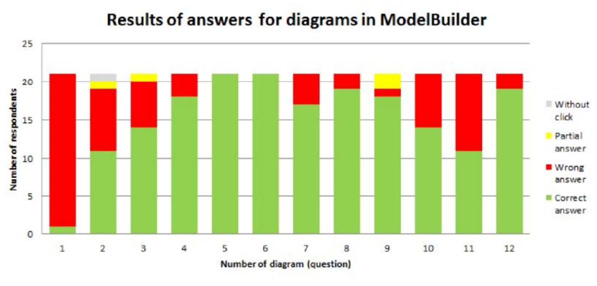

Figure 4. Graph of correct and incorrect answers from eye tracking testing of diagrams

Out of the total 21 respondents, 11 students completed the intelligence questionnaire. The results of their eye-tracking testing can be found in Table I. The table shows four parameters measured and processed by the SMI BeGaze program of SMI Experiment Suite. In addition, the table contains the number of correct and incorrect answers. In this case, there are 19 answers as some of the 12 questions had more than one correct answer (multiple correctly labeled symbols in a diagram).

TABLE I.
RESULTS OF EYE-TRACKING TESTING OF 11 RESPONDENTS

Resp.	Total time of the test [ms]	Blink count	Fixation count	Scan-path length [px]	Number of correct answers	Number of wrong answers
P03	80 783	7	276	28 499	15	4
P04	71 894	0	211	24 407	17	2
P06	133 334	27	371	43 240	17	2
P07	103349	12	290	32 990	18	1
P09	89 592	4	238	27 759	16	3
P10	70 379	11	233	27 439	17	2
P13	94 670	3	332	38 178	16	3
P14	101 128	18	282	34 436	19	0
P15	127 879	27	294	31 644	17	2
P19	95 936	19	256	33932	15	4
P20	61 612	2	168	17801	10	9

Table II. contains the results of intelligence questionnaire for the same 11 respondents. In order to be able to commensurate individual intelligences, their absolute values have been transferred to percentage ratios of intelligences for each respondent.

TABLE II.
RESULTS OF THE INTELLIGENCE QUESTIONNAIRE OF RESPONDENTS IN THE WORKFLOW DIAGRAM TESTING

Resp.	Lang	Music	Math	Vis	Mot	Inter	Intra
P03	13	18	14	16	14	11	14
P04	17	16	13	12	15	14	14
P06	15	13	15	16	14	13	14
P07	14	11	17	15	14	15	15
P09	15	12	17	16	12	15	14
P10	13	14	17	16	13	14	15
P13	11	16	15	16	18	12	12
P14	11	12	18	20	13	12	15
P15	10	14	16	16	17	14	13
P19	13	14	16	15	15	15	12
P20	15	11	15	15	18	12	12

The questionnaire clearly shows that for students of geoinformatics visual intelligence is predominant. Students take cartography courses in the first two years, and are skilled in reading maps. Furthermore, students perform digitalization of spatial data and their visualization in other numerous geoinformatics courses. Therefore their visual intelligence is actively developed during their studies. Language intelligence is used for reading text in the diagrams. Many elements are presented via text – input and output data, name of the spatial function (Buffer, Clip, Dissolve), they are located inside the graphic symbol (Fig. 2).

B. Experiments with Concept Maps

In 2015 in eye-tracking laboratory at University of Ostrava, pilot testing of 5 students of informatics was done on cognition and processing of information in Atom concept map. During the eye-tracking testing, respondents were given two tasks, which represented different cognitive levels of work:

1. *State the value of proton and electron charges. Compare the two values. Express your comparison using words.*

   The first question asked mapped the basic orientation in the text and was oriented towards the central topic of the exposed page.

2. *Why are atoms electrically neutral?*

   Based on clues in verbal or visual fields, students needed to deduce additional information. By having to complete, compare and combine facts, respondents were forced to use demanding logical mental operations.

TABLE III.
RESULTS OF THE INTELLIGENCE QUESTIONNAIRE OF RESPONDENTS AND TIME OF TASKS IN CONCEPT MAPS TESTING

Resp.	Lang	Music	Mat	Vis	Mot	Inter	Intra	Time of task 1 [s]	Time of task 2 [s]
R1	15	14	15	14	13	14	16	56	50
R2	12	11	17	17	17	14	12	46	37
R3	17	13	17	13	12	15	13	62	57
R4	16	13	14	13	13	16	13	51	33
R5	15	10	15	16	16	14	13	74	46

Table III. contains the results of intelligence questionnaire for the 5 respondents of concept maps cognition test. Absolute values of each intelligence have been transferred to percentage ratios of intelligences for each respondent.

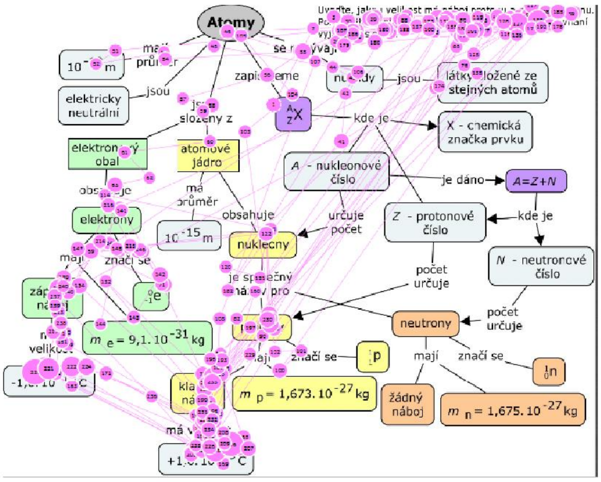

Figure 5. Gaze plot of the Atom concept map of respondent R1

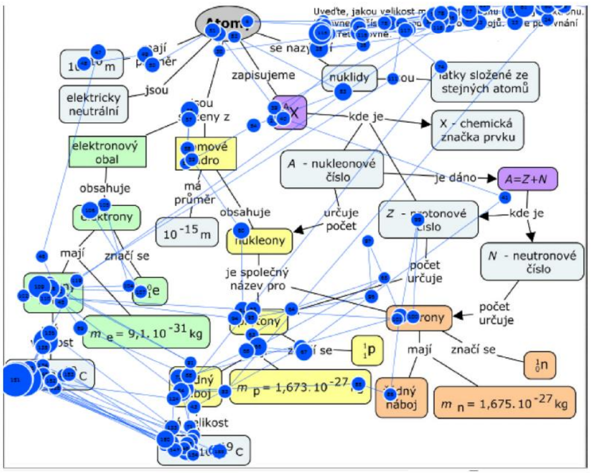

Figure 6. Gaze plot of the concept map Atom of respondent R2

Figures 5 and 6 show gaze plots of two respondents who read the same concept map differently. Respondent R1 in Fig. 6 does not scan the whole concept map, but only focuses on the right places, but keeps getting back to the question (upper right). Respondent takes longer time solving the question.

Respondent R2 in Fig. 5 first reads the question, scans the whole concept map and then, without returning to the question, selects the correct parts of the concept map (i.e. parts that contain relevant information) and answers the questions. Respondent is able to finish in a short time (see Table III.).

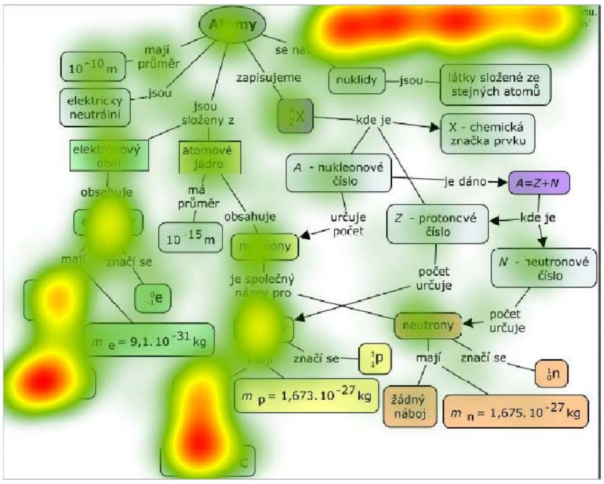

Figure 7. Heat map of task 1 of the concept map Atom

Fig. 7 shows the heat map of all respondents solving the 1st task. Since the task's solution can be found directly in the concept map in the bottom left corner, we see the largest focus being on the text of the question and the part of the concept map containing the solution to the first task.

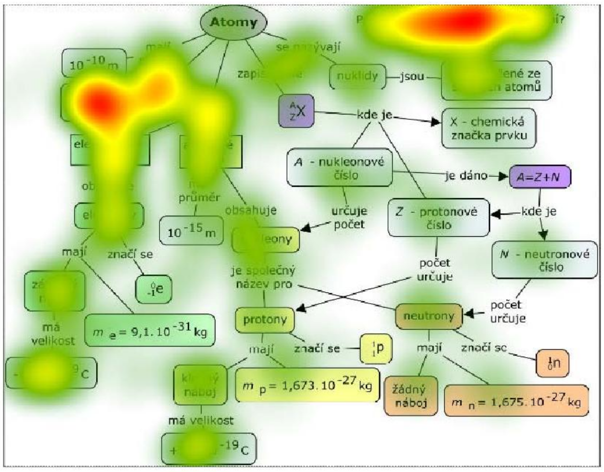

Figure 8. Heat map of task 2 of the concept map Atom

Fig. 8 shows the heat map of all respondents solving the 2nd task. This task's solution cannot be found directly in the concept map; the respondent has to use higher cognitive operations such as completing, comparing and combining facts.

IV. Conclusion

During experiments on reading workflow diagrams and understanding concept maps we looked for possible links between the results and strategies of working with visual content and different types of intelligence (by H. Gardner) of respondents. It has been shown that visual and mathematical intelligences have the largest impact on effective reading and comprehension of graphic notations. The effectiveness, at a rather surprising degree, is also influenced by language intelligence; to the extent that it can compensate for lower degrees of visual or mathematical intelligences.

The results of carried out experiments confirm that correctly described diagrams and maps are key. For users with higher language intelligence, descriptions accelerate cognition of the diagram.

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REFERENCES

[1] S. Popelka, A. Brychtova, "Eye-tracking study on different perception of 2D and 3D terrain visualization" *Cartographic Journal*, 50(3), 2013, pp. 240-246.

[2] P. Kubíček, Č. Šašinka, Z. Stachoň, "Selected cognitive issues of positional uncertainty in geographical data", *Geografie-Sbornik CGS*, 119 (1), 2014, pp. 67-90.

[3] Z. Dobesova," Data Flow Diagrams in Geographic Information Systems: A Survey",*Conference Proceedings SGEM 2014, 14th International Multidisciplinary Scientific GeoConference* Volume I, STEF92 Technology Ltd. Sofia, Bulgaria, June 2014, pp. 541-548.,

[4] J. D. Novak, and J. Canas, *"The Theory Underlying Concept Maps and How to Construct and Use Them,"* Technical Report IHMC CmapTools 2006-01 Rev 01-2008, Florida, Institute for Human and Machine Cognition, 2008.

[5] J. D. Novak, and D. Musonda, "A twelve-year longitudinal study of science concept learning," *American Educational Research Journal,* 28 (1), 1991, pp. 117-153.

[6] D. P. Ausubel, *The psychology of meaning verbal learning*. New York: Grune and Stratton, 1963.

[7] D. P. Ausubel, *Educational psychology: A cognitive view*. New York: Holt, Rinehart, Wiston, 1968.

[8] E. Mechlova, M. Malcik, "Testing concept maps electronically," *Proceedings ICETA* 2011, Košice: 2011, pp. 137-140.

[9] W. Schnotz, "Toward an Integrated View of Learning from Text and Visual Displays". *Educational Psychology Review*, 2002, vol. 14, pp. 101-120.

[10] D. L. Moody, "The "Physics" of Notations: Toward a Scientific Basis for Constructing Visual Notations in Software Engineering," *IEEE Transactions on Software Engineering,* vol. 35, no. 6, 2009, pp. 756-779,

[11] A. Plháková, *Přístupy ke studiu inteligence*. Olomouc: UP FF, 1999.

[12] H. Gardner, *Dimenze myšlení*. Praha: Portál, s. r. o., 1999.

[13] H. Gardner, *Multiple Intelligences: The Theory in Practice. Basic*, 1993, New York.

[14] Howard Gardner's multiple intelligences [cit. 1.2.2015] Available: http://www.businessballs.com/howardgardnermultipleintelligences.htm#multiple%20intelligences%20tests

[15] A. O. Voßkuhler, "Description (for Version 2.5): a software to record, analyze and visualize gaze and mouse movements in screen based environments," Berlin, 2009 [cit. 2014-12-28]. Available: http://www.ogama.net/sites/default/files/pdf/OGAMA-DescriptionV25.pdf

[16] M. Malcik, E. Mechlova, Z. Sikorova, A. Mentel, "Analysis of visual perceptual patterns on screen using eyetracker technology," *12th IEEE International Conference on Emerging eLearning Technologies and Applications*, Starý Smokovec: Slovakia, 2014, pp. 311-318.

[17] K. Rayner, "Eye movements in reading and information processing: 20 years of research," *Psychological Bulletin*, 124, pp. 372–422.

[18] J. Hyona, J. Kaakinen, & R. Lorch, "Individual differences in reading to summarize expository text: Evidence from eye fixation patterns," *Journal of Educational Psychology*, 94(1), 2002, pp. 44–55.